



State of California
THE RESOURCES AGENCY

Department of Water Resources

BULLETIN No. 74-5

WATER WELL STANDARDS: SAN JOAQUIN COUNTY

Appendix E: Formation Testing

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MARCH 1965

HUGO FISHER
Administrator
The Resources Agency

EDMUND G. BROWN
Governor
State of California

WILLIAM E. WARNE
Director
Department of Water Resources

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APPENDIX E
FORMATION TESTING

Introduction

During the course of the San Joaquin County Well Standards Investigation it became apparent that there are several areas within the county where ground water quality has been degraded by improperly constructed and abandoned wells or by existing geologic and hydraulic conditions. One of these areas lies between Stockton and French Camp, and another near Tracy. Reports as early as 1955 indicated that water quality problems existed in the vicinity of Stockton. Recent findings confirm the existence of ground water problems. Therefore, within the framework of the well standards investigation a formation testing program was carried out in these areas.

Wells generally penetrate, and the casings are perforated into, several aquifers. Any or all of these aquifers may yield water to either an operating, or to an abandoned well. Any sample taken from a well is, therefore, generally a composite of waters from more than one aquifer. When the quality of this composite water is poor or degraded, it is not generally known from which aquifer the poor quality water originates. There are methods, such as electric logging, direct sampling, etc., to determine the water quality in any one aquifer during the drilling process; however, no established method is commonly in use to determine the quality of water in individual aquifers of an existing well.

The program undertaken during the San Joaquin County Well Standards Investigation by the Water Quality Unit of the Delta Branch in the spring of 1963 included the use of a "high volume formation water sampling device" in seven wells constructed by the cable tool method. The device was developed by Mr. Wessley W. Paulsen, consulting geologist, of Chico, California.

The Concept of Formation Testing

Formation testing consists essentially of pumping water from an isolated segment of the well casing, through the perforations opposite any one of the water-bearing formations penetrated by the well. Figure 1 shows a multiple aquifer well. Under ideal conditions there is no vertical water movement outside the well casing and the waters enter the well through the perforations only. Under these ideal conditions the water quality in each of the contributing aquifers can be determined by use of the "formation Tester."

In a well producing composite water of inferior quality not all of the contributing aquifers may yield water of equal quality. The practical significance of formation testing lies in the fact that each formation can be temporarily isolated and the quality of water in a single aquifer can be determined. If formation testing indicates that some of the aquifers are yielding poor water, the well may be improved by sealing off these aquifers to provide a composite water of acceptable quality. In the event that none of the formations yield water of acceptable quality, destruction of the well can be recommended.

An even more important potential application of formation testing is the isolation of formations yielding water of unacceptable quality within a larger area. If a sufficient number of wells within an area were tested, it might be possible to determine which formations and particular depth zones within the formations were responsible. Those depth zones might then be sealed off throughout the area covered by the testing. If waters from different aquifers could be directly compared and water quality characteristics of the various aquifers determined, the identification and correlation of these formations might be possible. During the formation testing program an attempt

MULTIPLE AQUIFER WELL

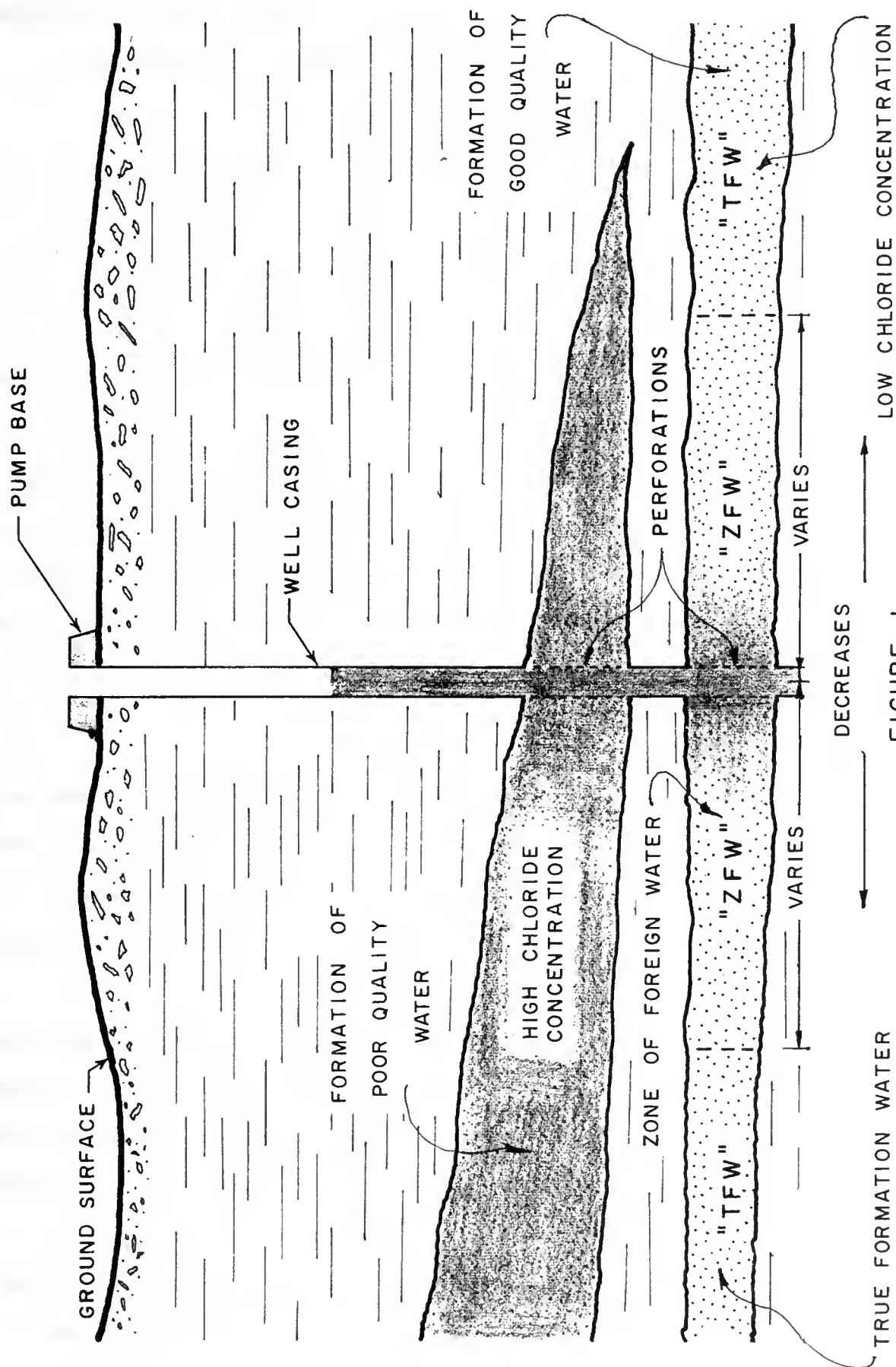


FIGURE 1

was made to achieve this goal. Details of the technique used are discussed under the heading "Chloride Concentration - Electrical Conductivity."

Testing Operations

The area selected for formation testing is located about five miles south of Stockton between the San Joaquin River and Highway 50. Numerous wells in the area producing poor quality water are interspersed with wells producing fairly good quality water. The water-bearing formations of the area consist of poorly interconnected, alluvial sand lenses laid down by the San Joaquin and Stanislaus Rivers.

The basic instrument used for formation testing was the formation tester. Before conducting the actual formation test in any of the seven wells tested, each well was probed with an instrument designed to record conductivity and perforation depth. Other instruments, such as flow meters to determine discharge, electrical tapes to measure water levels, etc., were used.

Conductivity Recording

Prior to the formation testing a specific conductance depth profile was run in most wells to determine the conductivity of the undisturbed static water column in the well. The data provided information on the quality of composite waters, and to some extent indicated the probable range of mineral concentrations.

The Instrument. The probe of the instrument used to obtain specific conductance profiles was custom built. Leads were connected to a Wheatstone bridge through a two-conductor insulated winch cable. The changes in current flow were amplified and recorded as a function of depth through a mechanically driven, Esterline-Angus graphic recorder.

The Conductivity Depth Profile. Specific conductance depth profiles are commonly made by lowering a probe down the well and measuring the

conductivity of water at various depths. This method does not insure that the obtained conductivity values are representative of the waters within the formations. In multiple-aquifer wells, waters of different formations are mixed within the casing and the measured conductivity values reflect this condition.

Specific conductance depth profiles were made in five of the seven wells that were formation tested and depth profiles in two of the five wells yielded usable data. Attempts in the other three wells were not successful. The usual causes of difficulty were probe contamination and instrument malfunction. Figure 2 shows four successive specific conductance and one perforation locator depth profile run in one of the two wells that yielded usable data. A certain amount of drift was noticed between runs, but since each run was preceded by recording of marks on the graph representing the conductivity of known solutions, the drift did not affect the readability. The drift was assumed to be caused by oil and other contaminants.

Figure 2 is a composite of the original charts placed side by side and aligned according to a depth scale, so as to facilitate analysis. Before reduction of the original charts the following was added: straight dashed lines to represent depths below the top of each well, numbers between the graphs to indicate numerical depth values, heavy arched lines to indicate the location of perforations. Numbers indicate the depth limits of each set of perforations, as reported on the well driller's log. The top part of the well is shown at the left of Figure 2.

A well has generally been subjected to composite pumping before a specific conductance depth profile has been run in it. Unless vertical flow takes place during periods of nonpumping, the water remaining in the casing will be composite water. Little knowledge of the quality of water of a given

SPECIFIC CONDUCTANCE AND PERFORATION LOCATOR DEPTH PROFILES

JUNE 1963

WELL NO. 1S/6E-10C2

RUN NO. 1

RUN NO. 2

RUN NO. 3

RUN NO. 4

PERFORATION LOCATOR

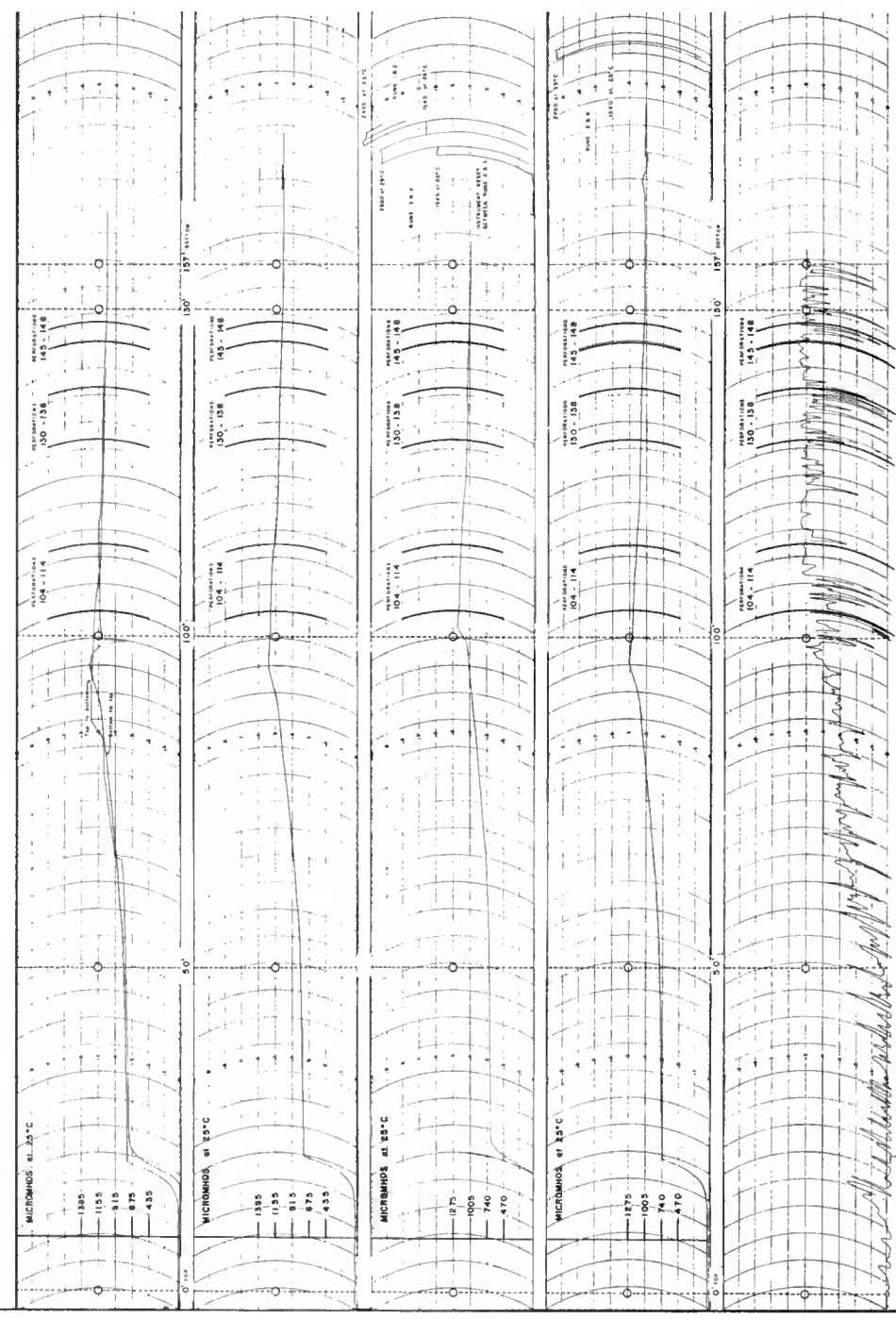


FIGURE 2

formation can be obtained before the water of that formation is isolated from the other waters which contribute to the composite water within the well.

The conductivity profile is at best only an indication of what can be expected from a series of formation tests in the well. On the other hand, the profiles have definitely shown the quality of the static water column in the two successfully tested wells. The profiles also indicated "Top Water Effect" (refer to "Glossary") and supported the results of the actual formation tests.

Perforation Locator

Perforations can be located with the aid of a special photographic or television camera. The use of cameras is a proven but expensive method of determining the exact location of perforations. There are other crude methods but none of them are dependable and satisfactory. The application of a collar locator for the purpose of locating perforations is probably new.

The perforation locator was used in six wells in order to provide a basis for comparison between the available well log and the actual conditions. Normally, well logs are the only source of information for the location of perforations; however, data presented in them are often not sufficiently accurate. Therefore, this operation attempted to determine if the use of a perforation locator could yield satisfactory information when no well log was available.

Only those wells whose logs were available were selected for the operation. Each well was at least several years old. Their condition was unknown prior to the actual formation testing.

The Instrument. The Lane Wells Induction Type Collar Locator was used as a perforation locator. The probe is an induction coil located between two permanent magnets about 24 inches long and one and one quarter inches in

diameter. As the probe is moved up and down inside the well casing a current is generated within the induction coil. This current is amplified and recorded. In this operation an Esterline-Angus recorder was used.

Changes in the current flow are caused by variations in the mass of the well casing and its distance from the induction coil. The probe indicates a collar by recording an increase, and a perforated section of the casing by a decrease in the electric field. Since both the volume of field conductor and its distance from the probe affect the current flow, the current generated shows abrupt changes as it nears a collar or a perforation.

The Perforation Locator Depth Profile. Perforation locator depth profiles were made in six of the seven wells that were formation tested. Figure 3 shows the best results from the perforation locator on five wells. The figure has been compiled from the original charts in the same manner as described previously for the conductivity depth profile.

Of the five graphs shown on Figure 3 the graph for well 1S/6E-10C2 shows the best agreement with the information reported on the driller's log. The closely spaced, long arcs which extend towards the bottom of the figure indicate perforations as recorded by the perforation locator. The maximum difference between the graph and the log is about three feet. This error could have been caused either by the use of different reference points or by inaccurate measurements by the driller. On this graph, and others, short arcs appear with more or less consistent length and regularity at approximately each four feet. These marks are apparently caused by the joints in the well casing. During the formation tests all three aquifers yielded waters of different quality at the perforation depths indicated.

Test data from other wells were not always consistent. The following is a brief evaluation of data obtained from another well.

PERFORATION LOCATOR DEPTH PROFILES

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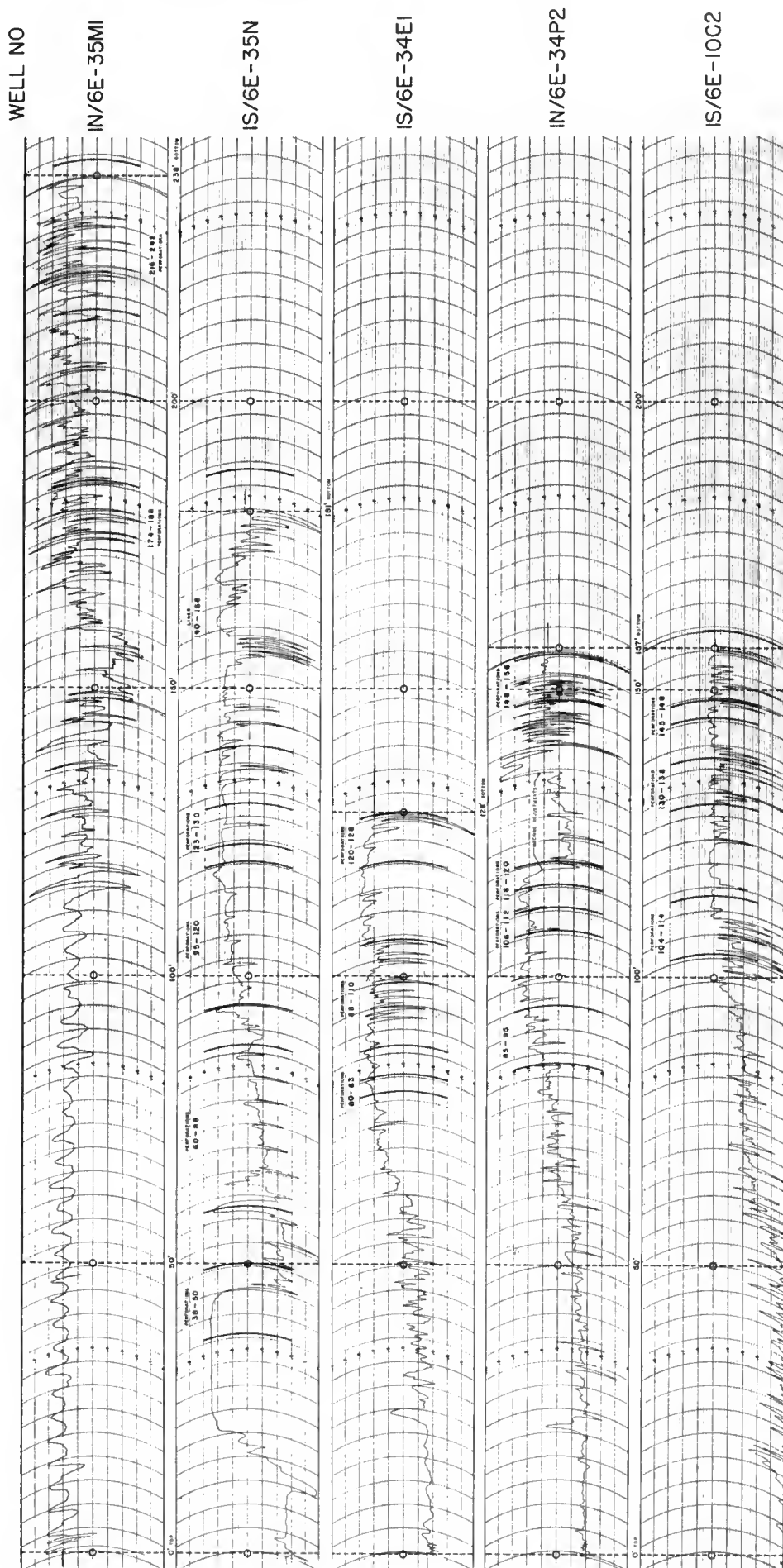


FIGURE 3

In well 1S/6E-35N, the perforation locator depth profile did not indicate perforations at any of the upper four perforated intervals indicated in the well driller's log. During formation tests the well did not yield water from any of these perforated intervals which could mean either that the well log is incorrect and there are no perforations present, or that the aquifers opposite the alleged perforations would not yield water under test conditions.

The perforation locator tests have proven the usefulness of the induction type collar locator; however, experience with the instrument and method led to the realization of its shortcomings. In a number of instances it was difficult to obtain the same results on two or more successive test runs in the same well. The probe could not be held in the center of the casing. In wells that were not straight or vertical the probe was apparently forced to slide along one side of the casing, etc. Even though the formation tests in each well more often confirmed the best perforation locator depth profile runs than confirmed the driller's log, the data were considered insufficient in number to conclude that the results are more reliable than the well logs, and were used during the field work only as a check. It is believed that further, more refined application of the induction principle should yield information sufficiently reliable to locate perforations in wells for which no driller's log is available.

Formation Tester

Based on the available information concerning the wells to be tested, and the supplementary data gathered through the conductivity recording and collar locator operations the actual formation test was set up. Figure 4 shows the arrangement of instruments used in this phase of the testing operations. The principal objective was to pump each aquifer to obtain isolated formation samples at predetermined time intervals.

FORMATION TESTING LAYOUT

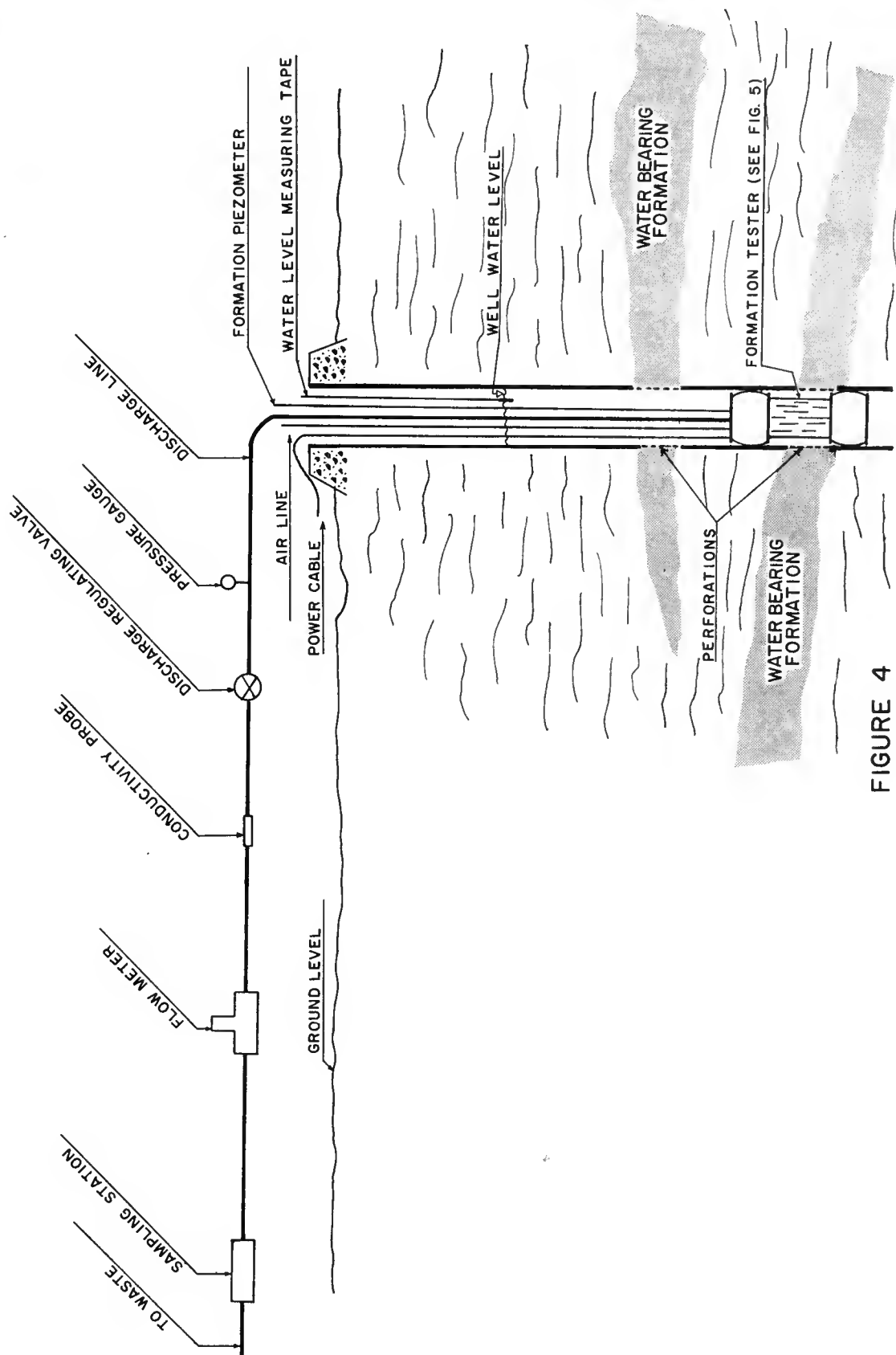


FIGURE 4

The Instrument. The "Formation Tester" shown on Figure 5 consists basically of a submersible pump housed in a perforated cylinder equipped with inflatable rubber "packers." Steel plates with diameters slightly larger than the diameter of the deflated packers provide protection to the inflatable rubber. A submersible pump is mounted within the cylinder. An air line, piezometer line, pump discharge pipe, and electrical power cable lead through the top steel plate from inside the tester. The air line is connected to both the top and bottom packer and provides air for simultaneous inflation of both. The length of the tester is 17 feet and it weighs approximately 400 pounds.

The tester is lowered into the well to the required depth and the packers are inflated to a pressure exceeding the hydrostatic pressure by approximately 60 psi. This excess pressure was considered safe for the packers and sufficient to prevent leakage between the packers and the well casing. Pumping from the space between the packers causes the formation to yield and after a lapse of time true formation water may be pumped. This time lag depends on the extent of the zone of foreign water, the permeability of the formation, hydrostatic pressure, area of perforations, construction of well, etc. The hydrostatic formation pressure causes the water to rise in the piezometer line. The formation pressure, represented by the water level within the piezometric line, may be determined and continuously monitored by means of an electrical tape lowered inside the piezometer line.

Formation Testing Procedure. In order to determine the nature of the problems in individual wells, efforts should be made to simulate "normal" pumping conditions. The location of the tester within the well casing is of primary importance to the success of the tests. The two packers of the tester should span all of the perforations opposite a given formation in order that the formation may be subjected to the same conditions that exist during

FORMATION TESTER

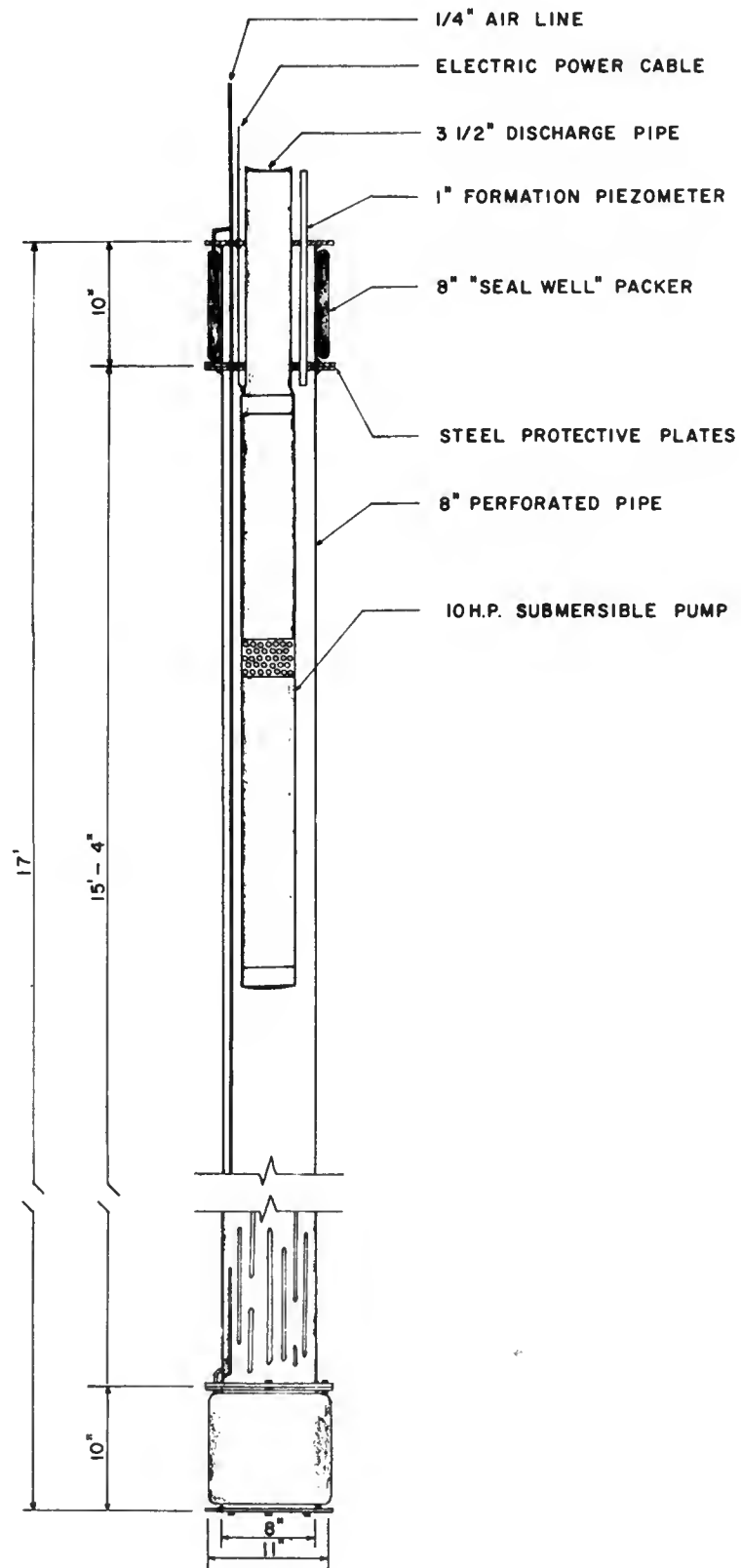


FIGURE 5

"normal" pumping. In a perforated interval of the well casing the flow is controlled by the area of the open spaces and the yield of the formation. If during the pumping the formation yields sufficient water to let the full thickness of the formation surrounding the perforated area of the casing remain saturated, the limiting factor will be the area of the perforations in the casing. If the drawdown extends below the top of the perforated interval, a portion of the perforations become inoperative, i.e., water does not flow through the perforations. When the perforated interval exceeds the span of the tester only part of the formation is pumped and only a portion of the perforations will be operative. In such case the top packer of the tester should be placed just above the top of the perforated interval. Although similitude between "normal" and test pumping will not exist, pumping water from above the packer and through the perforations above, will be prevented. Should the perforated interval be two or more times the span of the tester within the same aquifer, pumping around the middle and the bottom of the interval may be advisable.

Water-bearing formations yield water because the pressure is reduced within the well during pumping. Insufficient reduction of the pressure would result in true formation water not being produced within a reasonable time, or if the pressure were insufficient not yielding at all. The physical conditions of a well do not permit direct measurement of the velocity or of the area of yielding cross section. Discharge, however, can be readily measured and adjusted; thus determination of a proper discharge rate can provide similitude. The proper discharge rate is the value which causes the "normal" pressure to develop at the formation. The "normal" pressure was taken to be the pressure that would cause the same drawdown that occurs during "normal" pumping. The pressure in the formation, represented by the water level in the piezometer tube during testing, was measured as the distance

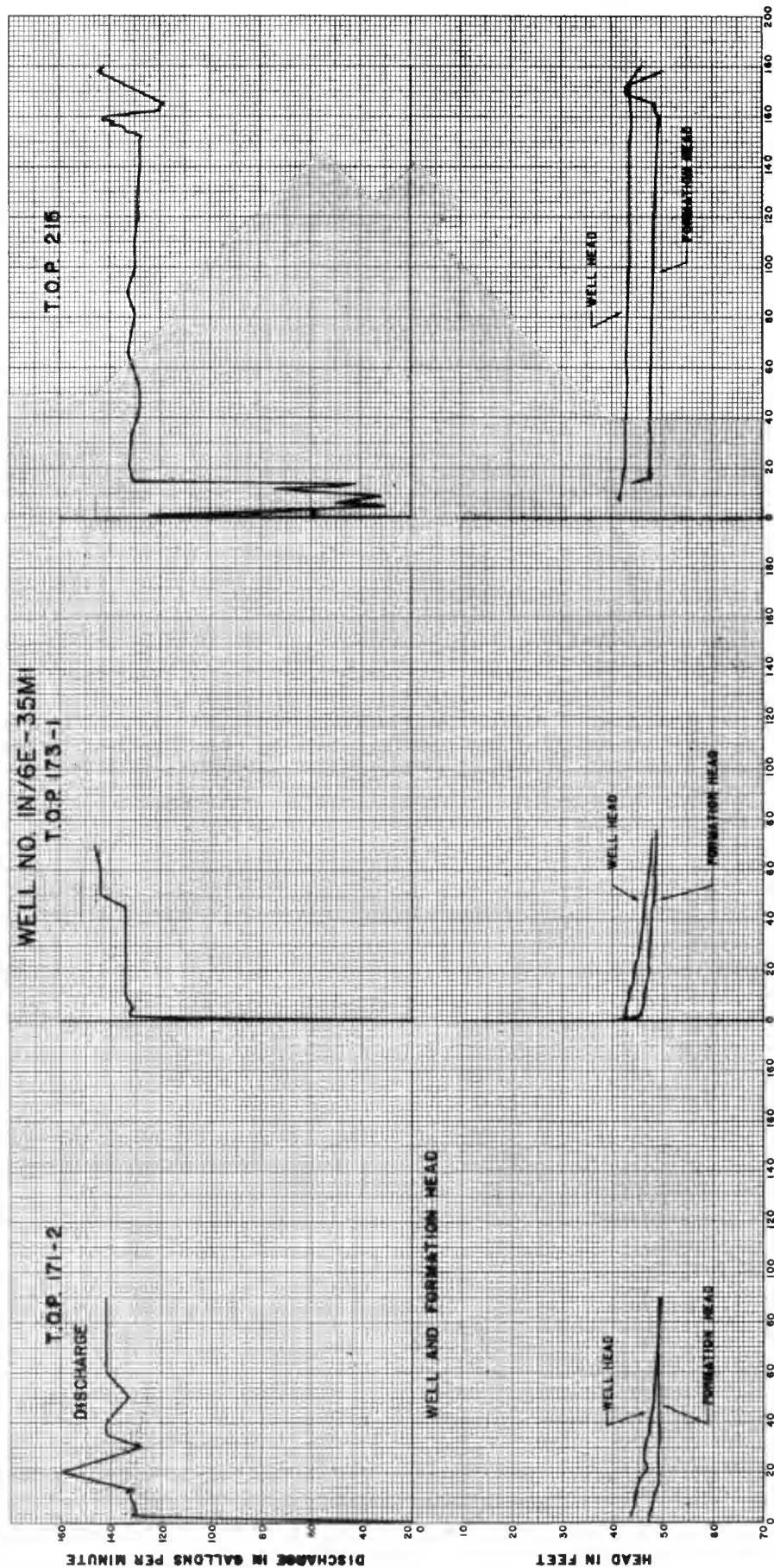
from the top of the well to the surface of the water standing in the formation piezometer tube. The discharge was measured with a Sparling Flowmeter and adjusted until the correct drawdown was achieved. Unfortunately, the submersible pump in the formation tester was insufficient to produce the normal drawdown in all of the formations and in some formations exact similitude of normal pumping conditions became impossible.

Excessive discharge rates cause extensive reduction of the pressure between the packers and may result in the collapse of the well casing. To insure against such a mishap the head on the formation within the well should not be permitted to become less than the head that occurs during "normal" pumping. This was the prime consideration for adding the piezometric tube to the original formation testing device. The method of conducting the head measurements was to lower a Fisher Electric Tape inside the piezometric tube to the "normal" drawdown. If the ammeter on the tape indicated that the water level in the piezometric tube dropped below the "normal" drawdown, the pump was stopped and restarted with reduced discharge rate. Simultaneous measurements of the water level within the well casing were also taken. The head differential that developed between the formation and the rest of the well (the pressure gradient across the packers) was instrumental in determining the pressure applied to the packers, and the volume of leakage associated with the pressure. Graphs of discharge rate, formation head, and well head versus time were prepared for each formation test. Figure 6 shows a typical graph.

A formation should be pumped until little or no change occurs in the quality of discharged water. Uninterrupted pumping of each formation was selected for the formation testing. This method provides a continuous quality versus pumping time plot for use in studying the behavior of the well. The water last pumped after the quality of discharge has become stabilized is

DISCHARGE, FORMATION HEAD AND WELL HEAD

JUNE 1963



TIME IN MINUTES

FIGURE 6

assumed to be the true formation water. It best represents the major portion of the water which is likely to flow from the formation to the well during a period of prolonged pumping.

As the formation tester is lowered into the well the water at the top of the static water column enters the tester. A portion of the entrapped water remains in the discharge pipe and between the body of the submersible pump and the unperforated part of the cylinder. This top water is generally of different quality than that pumped from the formation. Analysis of the formation testing data confirms this "Top Water Effect" phenomenon. Water pumped during the first 15 or 20 seconds represents the approximate volume of water contained within the discharge pipe and the 8-inch perforated cylinder of the tester. This water should be generally, but not necessarily of better quality than that in the rest of the well. One possible explanation for this quality difference is that the water originates either from leaks, such as imperfect welds in the casing above the static water level, or from surface water entering directly into the well. In wells located in problem areas the surface water tends to have better mineral quality than the composite water. The rate at which the higher quality water leaks in would not necessarily have to be high because a certain volume of water on the top of the well is never exposed to pump suction and therefore, never removed.

The following is a brief presentation of the results obtained from the formation testing of three of the seven wells. Generally the bottom formation was tested first and the tester reset at each formation progressing upward. Table 1 shows a summary of well data and test results.

In well 1N/6E-35M1, during the TOP 215 (refer to Glossary) formation test at the 216-242 perforated interval, the water pumped in the first few seconds had a Cl concentration of 275 ppm, and after 30 seconds increased to

TABLE 1

FORMATION TEST DATA

Well Data - Basic Information				Formation Testing Results			
:	:	:	:	:	:	:	:
Well number	Log	Actual:Conductivity:Chloride	Perforations	Number	Time	end of test runs	Conductivity: Chlorides
1N/6E-35M1	242 238	1560 390	176-186	TOP-171 TOP-173 TOP-215	90 75 180	1680 1650 1550	380 380 380
1S/6E-3M1	184 168	1547 431	118-120 165-166 168-180	TOP-109 TOP-151	90 120	2340 1440	700 440
Perforations covered with sand.							
1N/6E-34Q1	176 176	1604 424	90-103 122-130 148-162 164-170 104-114	TOP-87 TOP-118 TOP-148 TOP-155 TOP-101	8** 118 115 120 100	1700 1450 1550 1380 1320	435 425 425 375 305
1S/6E-10C2	192 157	1185 253	130-138 145-148 166-169	TOP-101 TOP-123 TOP-134	10 90 140	1300* 1200 1040	285* 260 240
Perforations covered with sand.							
1S/6E-34E1	132 130	800 154	80-83 88-110 120-128	TOP-74 TOP-95-1 TOP-95-2 TOP-95-3 TOP-111	Formation did not yield. 45 140 60 120	920* 920* 700 1000	230* 230* 145 260
1N/6E-34P2	190 157	3120 975	85-95 108-112 116-120 148-156	TOP-81 TOP-97 TOP-114 TOP-139	Formation did not yield. 70 150 130	2350 2850 2350	710 875 710
1S/6E-35N	255 181	--- 164	38-50 60-88 95-120 123-130 140-188	TOP-35 TOP-65 TOP-98 TOP-119 TOP-140 TOP-162	Formation did not yield. Formation did not yield. Formation did not yield. Formation did not yield. 45 120	720 720	150 165

*Composite samples.

**Formation was pumped dry after eight minutes.

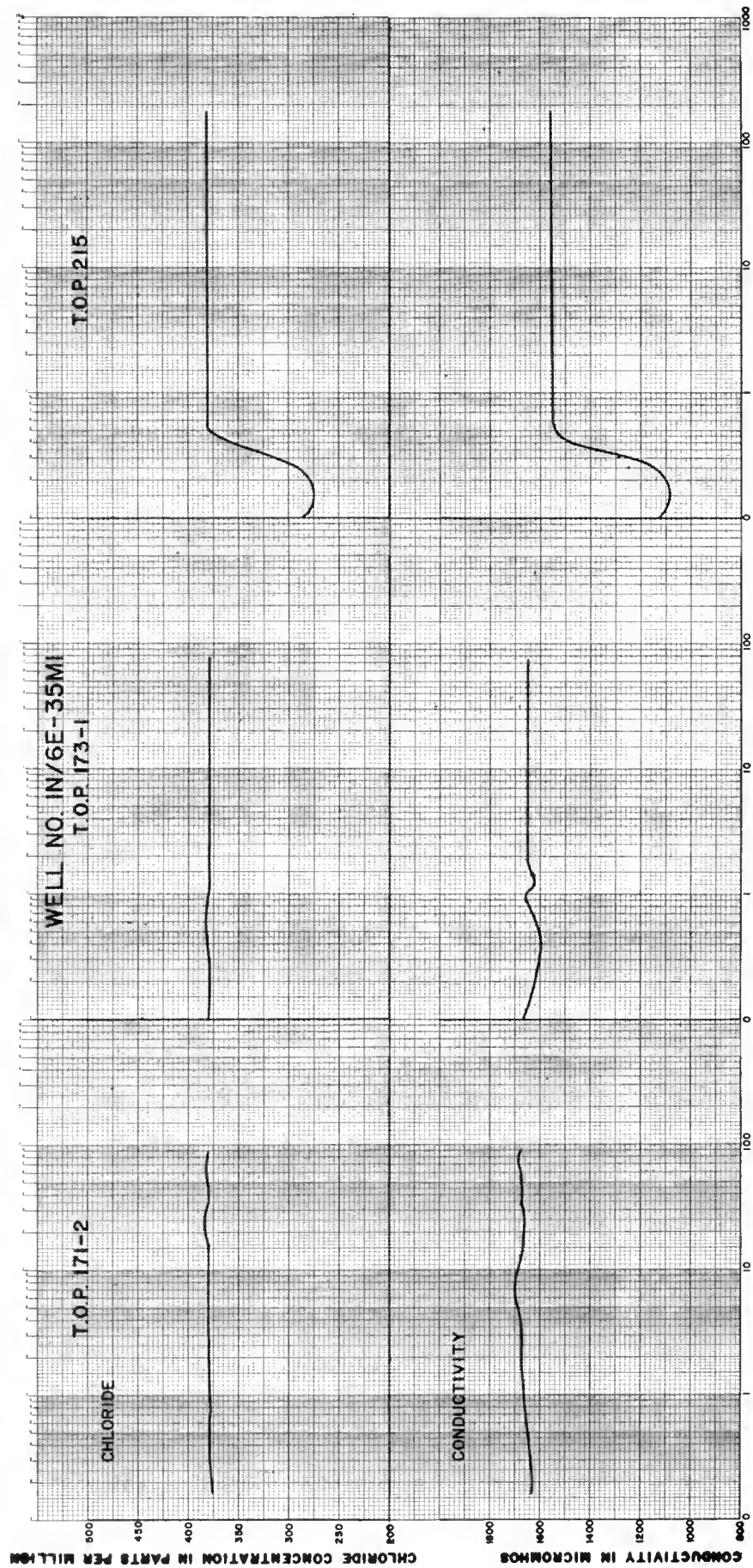
380 ppm, remaining at this value until the test was stopped at 180 minutes. This result indicates the top water effect. The true formation water obtained from the TOP 173, first test at the 176-186 perforated interval is of the same quality as that found at TOP 215. The top water effect is absent because the top water has been removed during the TOP 215 test. The water first pumped at TOP 173 is, and should be, of the same quality as that found at the end of the TOP 215 test because of the water remaining within the tester. Slight deterioration of the water quality can be observed at the TOP 171, second test. The Cl concentration increases from 378 ppm to 382 ppm, in 90 seconds. Figure 7 shows the data obtained from this level. The test on this well indicates that each formation yields water with the same Cl concentration. The aquifers are probably interconnected through sand lenses or have a common source of recharge.

In well 1S/6E-3M1 the formation tests showed that the top formation, at the 118-120 perforated interval, had poorer quality water than the bottom formation, located at the 165-166 perforated interval. The difference is 260 ppm Cl. The poorer quality water from the top formation apparently intruded the bottom formation and displaced some of its native water, thus creating a "Zone of Foreign Water" of inferior quality. The movement of the upper formation water into the lower formation is caused by a difference in formation head between the two aquifers (in an area of free or semi-confined ground waters the head of the better quality aquifers tends to be lower than the head of the poorer quality aquifers because intensive pumping from wells located in the good quality water-bearing formations results in a greater draft on the better water). The quality of water obtainable from this well could be improved by sealing the 118-120 perforated interval.

The formation testing results shown in Table 1 for well 1N/6E-34P2 may appear to be contradictory because the chloride value for composite water

CHLORIDE CONCENTRATION - ELECTRICAL CONDUCTIVITY

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TIME IN MINUTES

FIGURE 7

was higher than the chloride values in any of the individual formations.

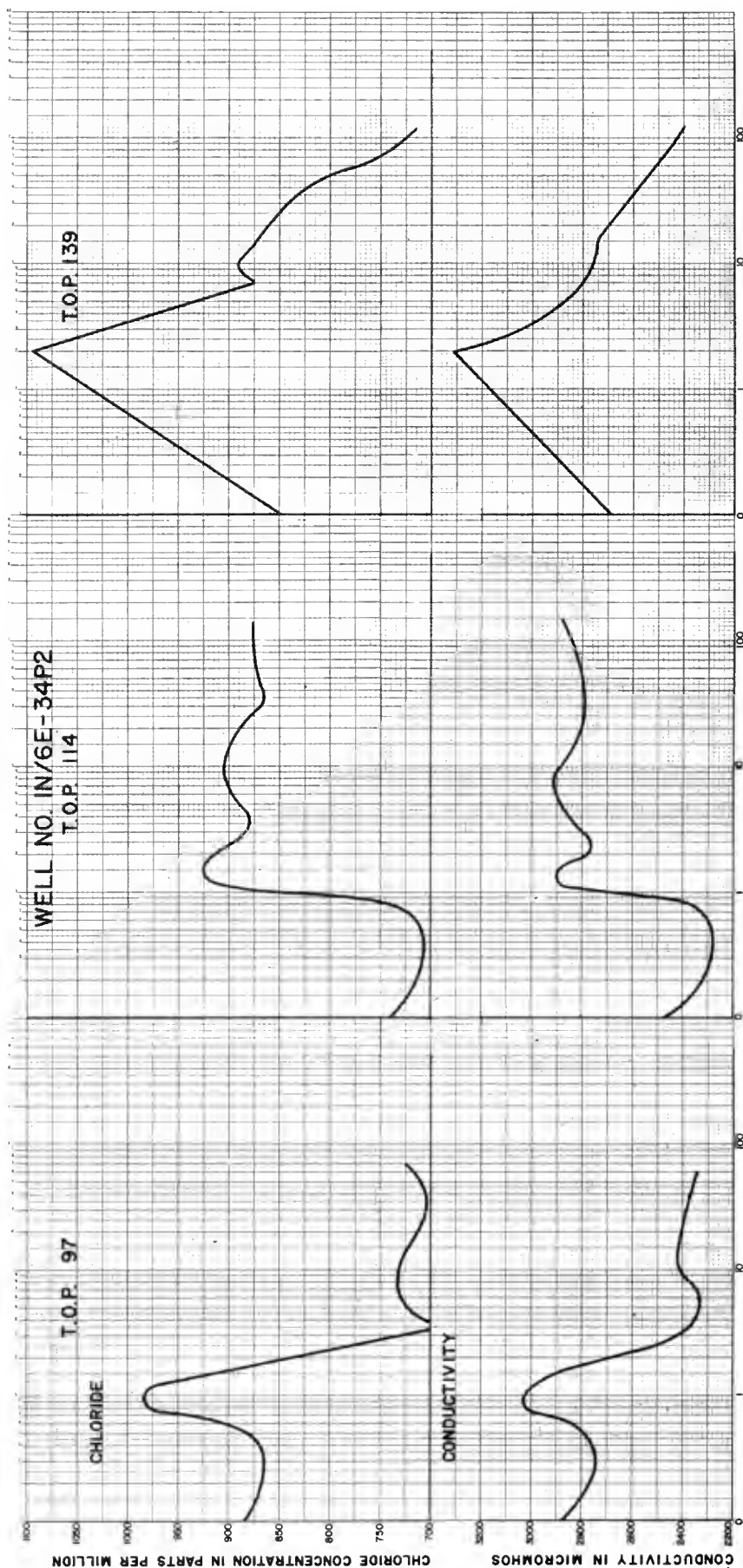
Observation of Figure 8 reveals, however, that the final formation test results were not the maximum values obtained during the tests. The maximum chloride concentrations occurred between the first and second minutes of pumping. The presence of these high chloride concentrations in the "Zone of Foreign Water" may result from salt accumulation during periods of non-pumping, from intrusion of poor quality water originating in other formations and entering the well through unknown perforations or leaks in the well casing.

Effectiveness of Packer Seal. Effective sealing at the two 8-inch seal well packers was a prerequisite for successful formation testing. Attempts were made to determine the efficiency of seals, using three independent procedures.

Fluorescein Dye Test. A more than sufficient amount of fluorescein dye was placed in well 1S/6E-34E1 following the TOP 111 test. The reason for using larger amounts of dye than necessary was to permit visual inspection of the color changes in the discharge. If the packers were sealing properly the dye concentration should decrease and eventually disappear as the formation was being pumped, but would remain virtually undiluted in the rest of the casing and formations. When the tester was reset opposite other perforations the first water pumped should have had about the same color as the original concentration in the well, and again gradual clearing should have occurred as the formation was pumped. It was recognized that some of the dye diffused through the perforations and would dye a portion of each formation. Because of technical difficulties encountered at the TOP 95 level, the results of this test were not as conclusive as they might have been; however, there was a definite indication that the packers were sealing sufficiently well. No conclusions could be reached concerning the efficiency of seals or the rate of leakage.

CHLORIDE CONCENTRATION - ELECTRICAL CONDUCTIVITY

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TIME IN MINUTES

FIGURE 8

Chloride versus Time Test. The chloride versus time study of graphs prepared for each test run indicated that in some wells definite differences in water quality existed between different formations and that the chloride concentrations were a function of pumping time. Figure 7 is a sample of these graphs. It was concluded that the packers were successful in restricting the pumping to one formation. Again, no conclusions could be reached concerning the efficiency of seals or the rate of leakage.

Well Head and Formation Head versus Time Test. Graphs were also prepared showing well head and formation head as functions of time. The basic concept of a comparison test was that if a head difference existed across the packer (head difference = formation head - well head) and no change occurred in the well head measurement the packer was sealing perfectly. By this method, however, only the sealing efficiency of the top packer could be checked, and then only in those test runs where the formation tester was positioned at the uppermost formation. An efficiency check on formation tests, other than in the tester's top position of each well yields uncertain information because perforations above the top packer could influence the well head measurements. Changes in the well head measurements indicate the degree of leakage, assuming that no leakage occurs in the casing above the packer and that no surface water enters the well. The sealing efficiency of the top packer is shown in Table 2. This efficiency is expressed as the ratio of leakage to discharge. Assuming 100 percent efficiency at zero leakage, the formula used was:

$$\text{Efficiency (\%)} = 100 - \frac{\text{leakage}}{\text{discharge}} \times 100$$

TABLE 2

SEALING EFFICIENCY OF THE TOP PACKER

Well Number	Diameter	Head : difference	Change in : well head	Leakage : (gpm)	Discharge : (gpm)	Efficiency : (%)
1N/6E-35M1	14"	Start 4' Stop 0'	6.0'	.5	135	99.6
1S/6E-3M1	12"	Start 10' Stop 1'	15.0'	.8	155	99.5
1N/6E-34Q1	12"	1'	7.5'	.3*	155	99.8
1S/6E-10C2	12"	2'	2.6'	.1	140	99.9
1S/6E-34E1	12"	40'	0.0'	0*	85	100.0
1N/6E-34P2	12"	11'	3.0'	.3*	130	99.8

* Uncertain data because the well head measurements were influenced by perforations above the top packer. In cases where the uppermost formation did not yield, the data from the next formation was used and noted as uncertain data.

The table shows that the leakage at the top packer is extremely small compared to the average tester discharge rate. The degree of error caused by the leakage is well within the accuracy of the analyses of samples and it can be concluded that the packer seal was effective in isolating an aquifer.

Special Study

As mentioned earlier, chloride ion concentration and specific conductance are two of the most widely used indicators of the quality of water. The specific conductance of water is caused by ions of various minerals. One of these ions commonly present in the water is chloride, which has a high equivalent conductance; thus, changes in its concentration distinctly affect the total conductivity of the water.

The unusually large number of samples originating from only seven wells provided an excellent opportunity to examine the relationship between chloride concentration and the total electrical conductivity.

Chloride Concentration - Electrical Conductivity Ratio

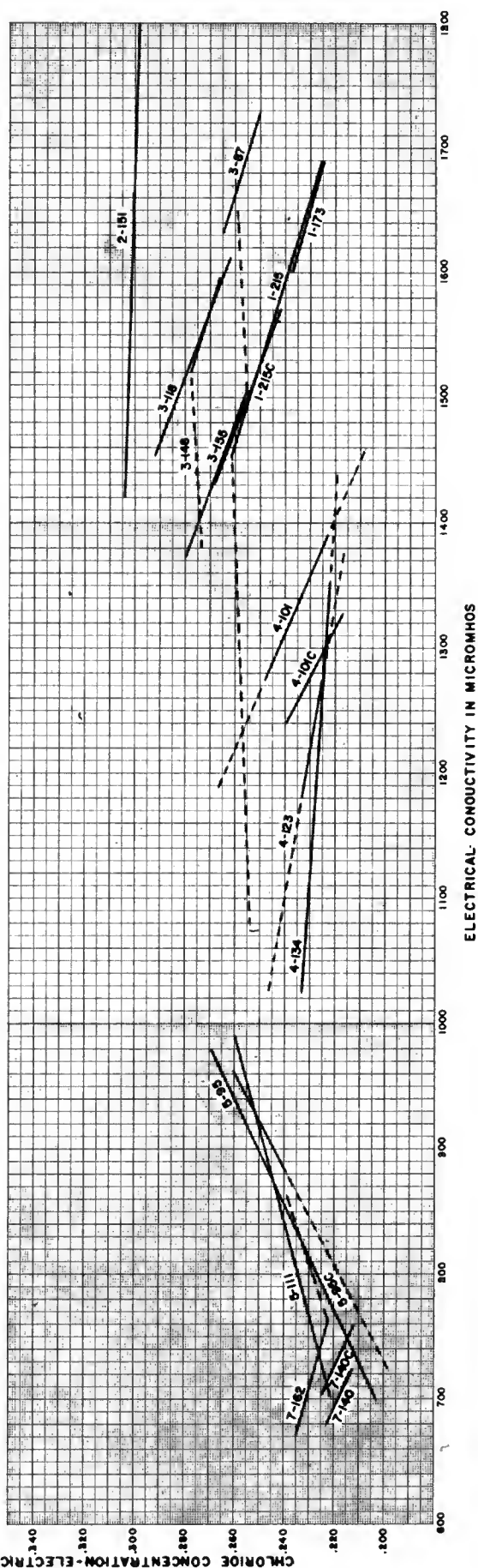
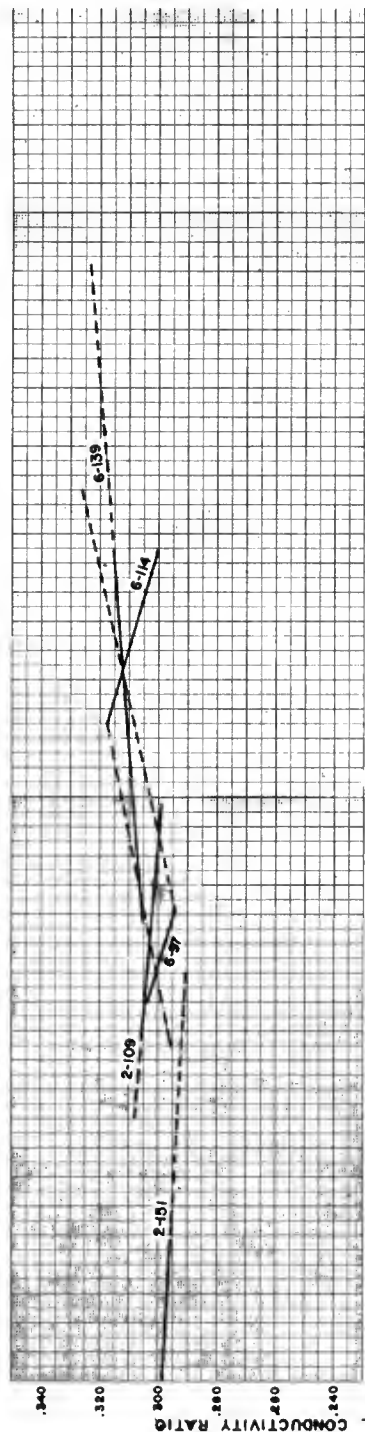
When the electrical conductivity of water is measured it is not known how much of this conductance is caused by the chloride ion and how much by the other mineral ions present in the sample. The term "chloride concentration-electrical conductivity ratio," represents the fraction of the total specific conductance caused by the chloride ion. This fraction is not constant and depends on the concentration of the other ions present in the sample. However, the chloride ion, due to its high equivalent conductance, generally has more effect on conductivity than any other single mineral.

Establishment of a relationship between the fraction of the total specific conductance caused by the chloride ion and the total conductivity of the samples would make the determination of approximate chloride concentrations possible when only one of the indicators, namely the specific conductance is available. Development of a set of curves represents an effort to establish this relationship. Figure 9 shows these curves for the wells tested during the formation testing.

Attempts were also made to correlate formations exhibiting identical chloride - EC relationships. It was presumed that if the water of a given formation in one well showed an identical chloride - EC ratio with that of a given formation in another well, that the formations were interconnected. After the curves (shown on Figure 9) were developed, it was found that the individual lines representing the chloride - EC ratio versus EC of each formation were different for each test. This result has been interpreted to

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FIGURE 9

indicate that none of the aquifers tested were interconnected. Such interpretation seems to be in line with the general geology of the area, which is not well defined. The attempts made to compare the available geologic information and well logs could not establish continuity of various geologic strata. The agreement between the indication of chloride - EC ratios and known geologic data would seem to confirm the absence of continuous strata within the study area and infers the presence of lenticular formations.

CONCLUSIONS

1. The geologic information used in this study was derived from well logs and previous investigations. The nature of the alluvial deposits make correlation of aquifers very difficult in the area of formation testing, where the water-bearing sediments have been deposited by the San Joaquin and Stanislaus Rivers, with probable contribution from the minor creeks north of the Stanislaus River. Due to these conditions water from the formations could not be traced from well to well and no determination could be made concerning the location or depth zones of either good or poor quality water within the area as a whole.
2. The formation testing of individual wells was generally successful. Samples obtained from different aquifers within the same well showed different qualities. In two of the seven wells tested (1S/6E-3M1 and 1S/6E-10C2) sealing of the poor quality aquifer could somewhat improve the wells.
3. Comparison of the pump discharge and leakage rates indicated that the packer seal was, in most instances, effective in restricting the pumping to one aquifer. The degree of error was negligible because the rate of leakage was well within the accuracy of sample analyses.

4. Data concerning the pressure between the inflated packers of the formation tester were found to be important and useful. This information was used to insure against collapse of the well casing, to determine the pressure gradient across the packer, and to establish a "normal" pumping rate for test conditions.

5. Time versus water quality plots indicated that the time of pumping was generally sufficient to remove foreign water from the aquifers adjacent to the wells. In most instances the "zones of foreign water" were found to be the result of interconnection of the aquifers within the well casing. The foreign water was generally removed during the first hour of formation pumping.

6. Specific conductance depth profiles of the static water column within the well casing successfully showed the change in conductivity as a function of depth in two of the six wells tested.

7. Perforation locator depth profiles successfully indicated most of the perforations as reported by the well drillers in three of the six wells tested.

8. Changes in the construction of the formation tester could improve its versatility and effectiveness. The more important of these changes are:

- a. Provision for independent inflation of each packer;
- b. Provision for a wide range regulation of the discharge rate;
- c. Provision to measure pressure conditions below the tester;
- d. Provision for continuous conductivity measurement of discharge.

9. Improvement of the instrumentation for both the collar locator and specific conductance depth profiles is desirable.

GLOSSARY

Appendix B, "Definition of Terms", of Bulletin No. 74-5 lists those terms which were used throughout the report. The following special terms and abbreviations were used in Appendix E and are defined as follows:

Composite Water - the mixed water pumped from the well, originating from and yielded by more than one aquifer. Normal pumping of multiple-aquifer wells produces composite water.

Formation Piezometric Head - a measure of the hydrostatic pressure existing between the inflated packers of the formation tester. The formation head is measured relative to the top of the well and is represented by the distance from the top of the casing to the top of the water standing in the formation piezometer.

Native Water - the water pumped from a formation, originating from and yielded by the same aquifer. Normal pumping of single-aquifer wells or formation pumping of one aquifer of multiple-aquifer wells produces native water when all foreign influence has been removed by the pumping.

"Normal Pumping" - the operation of the original pumping installation in the well. The word "normal" is used to refer to any operation or condition (such as "normal" pressure, "normal" drawdown, etc.) that generally occurs or exists when the well is being used under regular operating conditions.

Static State - the hydraulic condition of the well when no water is being pumped, regardless of whether or not flow occurs between different aquifers.

Top of Packer (TOP) - an abbreviation used in the formation testing operations. It is used to designate the depth at which the top packer of

the formation tester was located during testing. The abbreviation and a number (i.e., TOP 192) indicate that the top packer of the formation tester was located at 192 feet below the top of the well casing.

Top Water Effect - the effect that the different, generally higher quality, water from the top section of the water column within the well casing has on the formation test data.

True Formation Water (TFW) - water of a particular quality best representing the major portion of the water which is likely to flow from the formation to the well during a period of prolonged pumping; it is free of any significant amount of water of other formations.

Well Head - a measure of the hydrostatic pressure that exists in the well casing at points above the inflated packers. The well head is measured relative to the top of the well and is represented by the distance from the top of the casing to the surface of the water standing in the well casing.

Zone of Foreign Water (ZOF) - a portion of a formation saturated with water that is not true or native to the formation. Foreign water in a formation generally originates in another formation exposed to the well.

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